International Journal of Earth, Energy and Environmental Sciences
ISSN: 2517-942X
Vol:12, No:11, 2018

Eco-friendly and Cleaner Process for Isolation of Essential Oil Using Photovoltaic Energy: Experimental and Theoretical Study

Hanen Nafaa, Maissa Farhat, Sina Ouriemi, Sbita Lassaad

***Abstract*—**The use of renewable energies is growing significantly worldwide. Faced with the increasing demand for electrical energy, mainly for the needs of remote, deserted and mountainous regions, numerous applications use photovoltaic energy. In this sense, the proposed study concerns a mathematical modeling and an experimental validation for the recovery of essential oil by a steam distillation system using photovoltaic energy. In this paper, we proceed to a modeling of the solar system that includes a photovoltaic (PV) generator with an electronic power converter allowing a continuation of the optimum operating point. The results obtained are promising and are validated practically.

***Keywords*—**Boiling in tubes, DC-DC converter, desalination, maximum power point tracking command, photovoltaic energy, solar generator.

I. Introduction

NOWADAYS, the extraction of essential oils and flavors for the cosmetics, perfumery and agri-food industries, is carried out in two ways; either through hydrodistillation (called also steam distillation), or through solvent extraction. These traditional methods have been tested. They are expensive as they consume significant amounts of power and solvent. Energy generally comes from oil, which is increasingly criticized for its impact on health and the environment. Accordingly, an urge for the development of sustainable chemistry has risen. Yet, despite some technical developments aimed at its optimization and better control, the industrial process of essential oils extraction has little changed over the last fifty years.

Within the framework of "chemistry and sustainable processes", we have developed an extraction system for essential oils by means of a photovoltaic source called “photovoltaic steam distillation method” (henceforth, PVSDM). The method is based on the principle of hydrodistillation using a PV source.

Photovoltaic energy is an inexhaustible source of energy since it is derived from direct sunlight. Therefore, it respects nature and the environment. PVSDM is easy to transport and install, in addition, its maintenance cost is limited. Batteries are used to smooth PV output power or to maintain system operation when solar power is insufficient. The main disadvantage of this coupling is the high cost of the PV system when using an inverter. Thus, it has to use a photovoltaic system as a source of direct current.

This manuscript is composed of two parts, and it aims to present the mathematics of the design and the validation of this process. This system is used for the isolation of essential oils. It is clean and renewable. It is better compared to the conventional vapor diffusion system [1].

A PVSDM is usually built from the following major components, shown in Fig. 1. PVSDM system contains the following components:

- PV.
- A DC-DC converter (a controller that helps extract the Maximum Power Point Tracking (MPPT)).
- The spray chamber.
- The condenser.

The main advantage of this product lies in the heat produced by an electrical resistance which is given (or generated) by a photovoltaic source. This process is produced on a small scale. It is an environmentally-friendly desalination solution that addresses the main problems of the place, water, energy and environment [2].

II. Mathematical Modeling

A. Modeling the Global Solar Flux Density of the City of Gabès

In some works, the variation of the density of the solar flux is taken randomly [19], [20], while in others it is linked to meteorological parameters, such as cloudiness and humidity [3]. Accordingly, modeling the density of the solar flow is deemed necessary [4]. Having sufficient meteorological data on the city of Gabès, we proceeded to the choice of a model of adequate sunshine. Indeed, several works [5]-[7] have been done to test three models, known under the names: ASHRAE, DELORME and EUFRAT, adopted in the Mediterranean area. These works are concerned with the study of the variation of global solar flux density, calculated in terms of the density of the global experimental solar flux. After several works on solar models (ASHRAE, DELORME and EUFRAT), the EUFRAT model, was chosen for the calculation of the global solar flux for the city of Gabès, as this model was considered

H. Nafaa and L. Sbita are with University of Gabes, National Engineering School of Gabes, Street of Mednine 6029 Gabes, Tunisia (e-mail: hanen_nafaa@yahoo.fr, lassaad.sbita@enig.rnu.tn).

M. Farhat is with American University of Ras Al Khaimah, Sheikh Saqr Bin Khalid Rd - Ras al Khaimah, Émirats Arabes Unis (e-mail: maissa.farhat@gmail.com)

S.Ouriemi is with National Engineering School of Gabes, Street of Mednine 6029 Gabes, Tunisia (e-mail: soueriemi@gmail.com)

more efficient [8]. The EUFRAT model was developed to provide parameters required for any day of the year. The flowchart used in calculating the solar flux density for an inclined plane, is developed in Fig. 2.

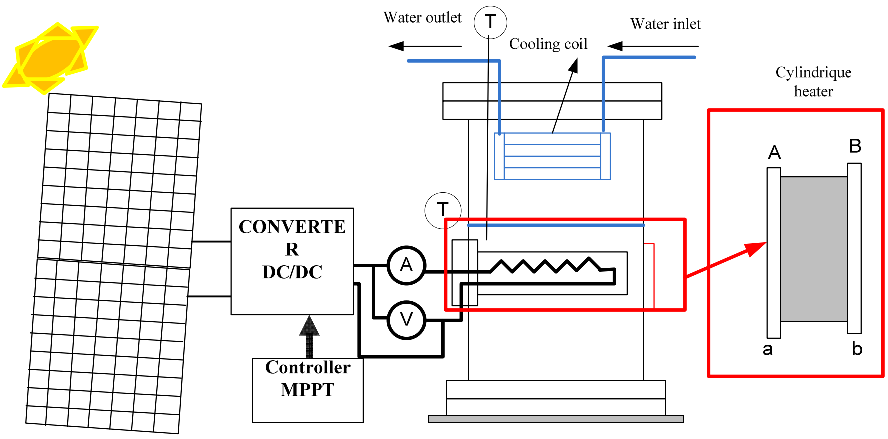

Fig. 1 PV SDM system

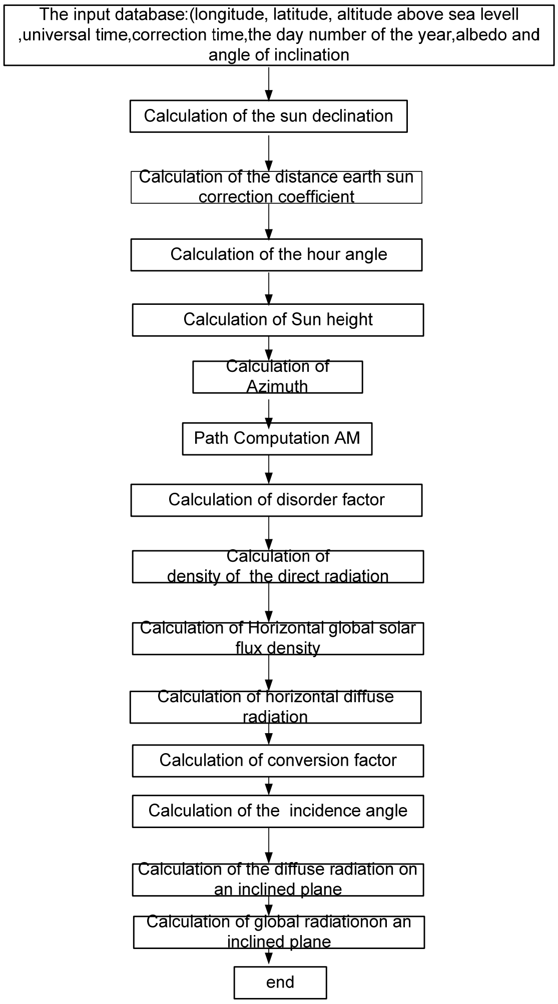

Fig. 2 Flowchart of the density calculation

To validate the model, we chose a typical day, the 20/07/2014. Fig. 3 shows a comparison between the experimental data and the calculated irradiation data.

B. Energy Source

Recently, there has been a growing interest in alternative energy sources, because fossil fuel plants and nuclear power plants affect the environment and its stability. Among the various sources of alternative energy, solar energy stands out as a source of clean and unlimited energy. A considerable amount of research has recently been conducted in this field.

Energy is produced by photovoltaic (PV) panels, consisting essentially of PV cells. These are electronic components, which transform sunlight radiation into electricity. They can also be considered as an ideal source of current that provides a current that is proportional to the incident light power.

The model associated with a diode, established from that of a PN junction, is characterized by its equivalent electrical diagram (Fig. 4). The main advantages of this process are shown in the product heat by electric resistor which is given (or generated) by a PV source. This process is produced on a small dimension. This process is an environmentally friendly desalination solution that addresses the major issues of the water–energy–environment nexus [9].

The energy input of the prototype system is the PV power. This energy can be calculated by:

$$P_{pv} = V_{pv}\ I_{pv} \tag{1}$$

The cell current is given by:

$$I_{pv} = N_p I_{ph} - I_d - I_{sh} \tag{2}$$

The diode current is given by [10]:

$$I_d = I_{sat}\left(\exp\left(\frac{V_{pv} + I_{pv} R_s}{T K n} q\right) - 1\right) \tag{3}$$

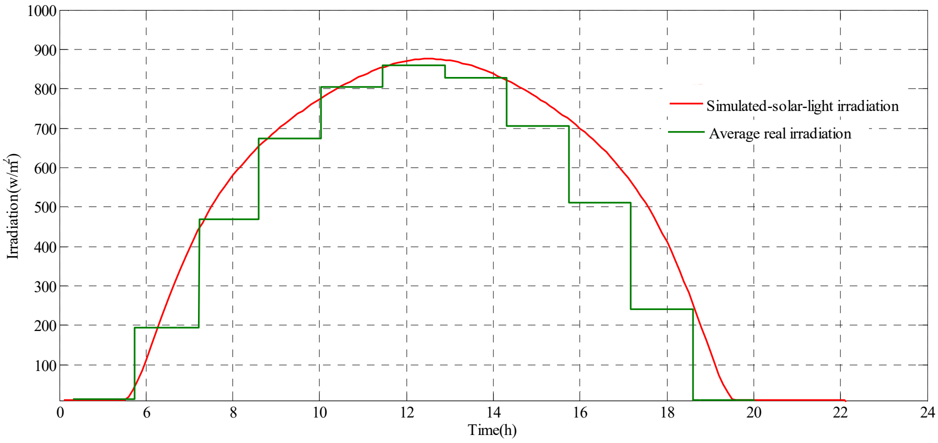

Fig. 3 Intensity of solar radiation according to time

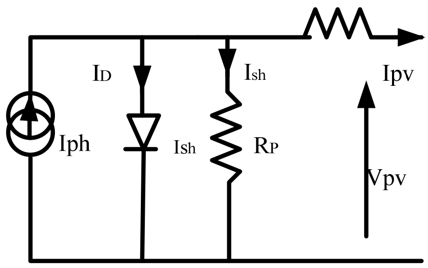

Fig. 4 Equivalent model of a PV cell

The reverse saturation current Isat, is dependent of temperature, the module current, Iph, can be given as:

$$I_{ph}=\lambda\left(I_{SC}+K_i\left(T-T_{REF}\right)\right) \quad (4)$$

with:

$$\lambda=\frac{G}{G_S}$$

The Shunt current is given by:

$$I_{sh}=\frac{\left(V_{pv}+I_{pv}R_S\right)}{R_P} \quad (5)$$

The meaning and typical values of the parameters given by (2) and (3) can be found in many places (see e.g. [11], [12]).

C. System Controller

One of the major problems of PV systems is that the output power of PV panels strongly depends on solar irradiation and ambient temperature. Therefore, the loads cannot be directly connected to the output of the PV panels. However, the direct interfacing between the PV generator and the load creates significant problems of mismatch, when the light intensity varies. The adaptation stage of the PV system consists of a DC-DC converter which allows the adaptation between the PV panel and the load (Fig. 5), in order to extract the maximum power of the panel. A boost converter produces a DC voltage by the PV panels at a charging voltage [13].

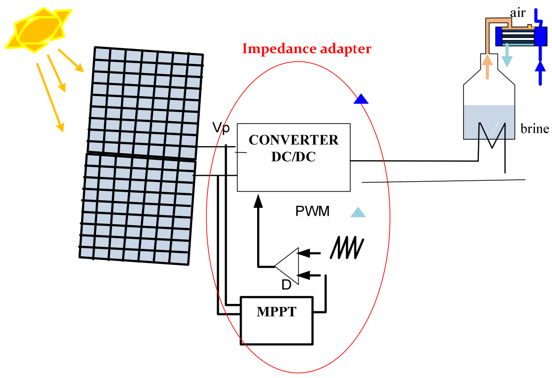

Fig. 5 PV distillation system with MPPT

The Boost converter is a DC-DC converter that increases its input voltage according to the formula:

$$V_c=\frac{1}{1-\alpha}V_p \quad (6)$$

Vc, Vp are respectively the voltage of the load, the voltage of the GPV and the cyclic ratio of the converter.

MPPT Control Algorithm (Perturb & Observation)

The discrepancy can be overcome by introducing a corresponding DC/DC converter, which continuously searches for the PWM of the PV generator. This converter can be controlled by a PWM controller.

One of the most widely used MPPT algorithms is the Perturbe et Observent (P&O [14]). It is based on the evaluation of the derivative of P against V. The sign of P/dV and the type of DC/DC converter used, determine the increase or the decrease of the working cycle of the converter, and thus, the point operating the PV module or the chain, in order to maximize the power produced.

The problem lies in the difficulty of designing and establishing a control that converges the PV system to optimal operating points, regardless of variations and load.

The method used to control the maximum power point is the Perturb and Observe (P&O) method. The latter is a widely used approach for determination of the maximum power point PPM.

Fig. 6 gives the PV power-voltage characteristic windup for the P&O algorithm. This latter is designed so that it operates on a calculator, and therefore, at each cycle of the algorithm, V and I are measured to calculate P (k). The value dP (k) is compared to zero.

If the output power has increased since the last measurement, the disturbance of the output voltage will continue in the same direction as that taken in the last cycle. If the output power has decreased since the last measurement, the voltage V of the panel is disturbed in the opposite direction to that of the previous iteration.

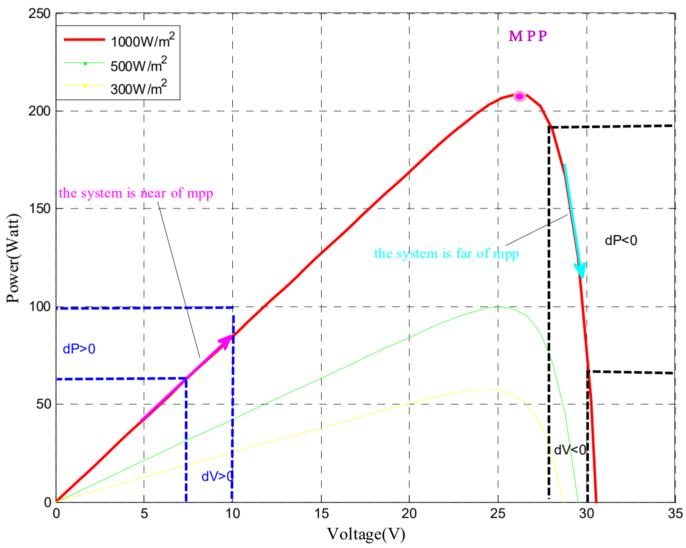

Fig. 6 Graph Power versus Voltage for Perturb and Observe Algorithm

D. Waste-Heat-Recovery Steam-Driven Thermal Desalination

The main component of the evaporator is a heating element by Joule effect. In this case, this resistance is the electrical charge of the PVG. Ppv is the dissipated electrical power in the resistor, which is related to the heat flux density q by;

$$P_{pv} = V_{pv} * I_{pv} = q * S * l = R I_{pv}^{2} \quad (7)$$

where d and l are respectively the diameter and the length of the wire with

$$S = \Pi \left(\frac{d}{2}\right)^{2} \quad (8)$$

With the resistance proportional to resistivity and the variation of temperature governed by the following law [15]:

$$R = R_0 (1 + \alpha \Delta T) \quad (9)$$

where R0, R are the wire resistances before and after heating, ΔT is the temperature variation and α is called the temperature coefficient of resistance.

The resistance before heating depends on ρ which represents the resistivity of the copper, the section and the length of the wire. Resistance can be calculated by:

$$R_0 = \frac{\rho l}{S} \quad (10)$$

In general, boiling steam occurs either on the outer surface of the submerged tubes or on the inner surface. The boiling of the pool refers to the vaporization that takes place on a solid surface submerged in a quiescent liquid. When the temperature (Ts) of the solid surface exceeds the saturation temperature (Tsat) of the liquid, vapor bubbles are formed at nucleation sites on the surface then grow and detach from the surface.

The temperature of the wire (Ts) is assumed to be constant. It is determined by the knowledge of its electrical resistance [16].

One of the first and most useful correlations for nucleate boiling was that of Rohsenow in 1952 [17]:

$$\frac{C_{pL}\left(T_S - T_{sat}\right)}{\Delta H_V} = C_{sf}\left[\frac{q}{\eta_L \Delta H_v}\sqrt{\frac{\sigma_L}{g\left(\rho_L - \rho_V\right)}}\right]^{\frac{1}{3}}\left(\frac{\eta_L C_{PL}}{\lambda_L}\right)^{n} \quad (11)$$

σ is the superficial surface tension between steam and liquid. The coefficients Csf and n depend on the Strong liquid interface; where all properties for liquid are at Tsat, the constant Csf is an empirical coefficient depending mainly on the surface condition and the nature of the liquid.

The exponent n depends on the type of fluid. For the water, we take n to be 1. Finally, we have [18]:

$$\left(T_s - T_{sat}\right)^3 = \frac{q}{\mu_L * \Delta H_v}\left(\frac{\sigma_L}{g\left(\rho_L - \rho_v\right)}\right)^{\frac{1}{2}}\left[\frac{C_{sf}\Delta H_V P_{rl}}{C_{pL}}\right]^3 \quad (12)$$

The surface tension of water in contact with its vapor can be calculated by:

$$\sigma_{water} = 235.8\left(1 - \frac{T_{sat}}{T_c}\right)^{1.256}\left[1 - 0.625\left(1 - \frac{T_{sat}}{T_C}\right)\right]\left(\frac{mN}{m}\right) \quad (13)$$

Tsat and Tc are expressed in K. The evaporation rate is calculated as:

$$\dot{m} = \frac{P_{pv}}{\left(\Delta H_V + C_P \Delta T\right)} \quad (14)$$

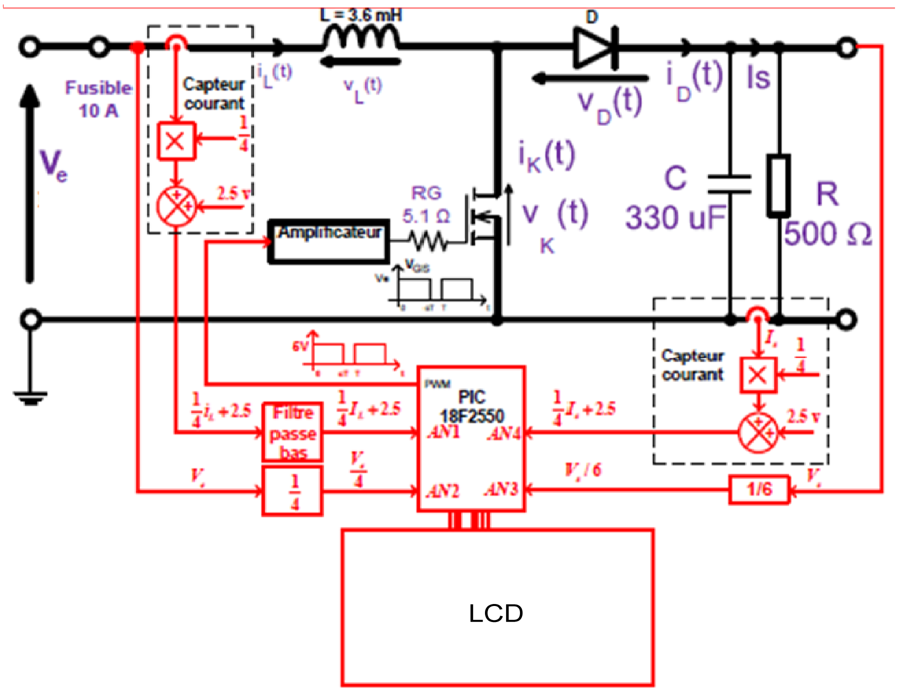

Fig. 7 BOOST converter

III. Experimental Study

A. Description of the System

The experimental platform is composed of commercial solar panels (PV modules), a boost converter, with a microcontroller, a current sensor, and a load (see Fig. 8). The output of the PV generator is connected to the input of the DC-DC converter and the output of the boost converter is connected to the load. The MOSFET used in the boost converter is Q5IRF 540. Fig. 7 shows some details of the DC-DC converter box. The current value is measured using the LA25 - N P sensor. We used an LCD with four lines of reference LM041L to display the input voltage values of the panel. The low cost microcontroller program is implemented through the software PIC CCOMPILER, to control the operating cycle of the DC-DC converter of the power supply to regulate the voltage. In addition, Visual Basic programming was used. The PWM frequency is 25 kHz.

Fig. 8 gives an idea of the experimental setup used for PV desalination. The initial solution is introduced into the glass boiler of a 200 cm diameter, which can contain up to 10 l. The initial temperature of the water is 20 ˚C. The formation of drops of distilled water occurs on the wall of a glass condenser.

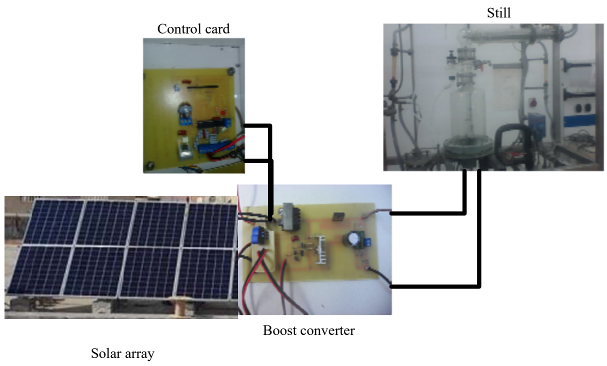

Fig. 8 Experimental setup of the water desalination system

For the installation of the power supply, we use PV panels which supply a voltage to the chopper boost. This converter is used to increase the value of the output voltage according to the input voltage, depending on the variation of the cyclic report. The controller board of the maximum power point is made from a PIC 18F 2550 microcontroller to control this chopper.

B. Experimental Study

An experimental study took place in June 2015, at the ISET of Gabès. The power supply used in this installation was four liters (4 liters) and the PV network was composed of ten PV panels connected in parallel series. Each chain consisted of five PV panels in series. The total power was 2000 W. We chose a typical half day in June, with an average solar irradiation of about 592 w/m^2 in our experiment. The irradiation is variable between 7:00 and 16:00. A glass boiler contained four liters (4 liters) of water. This water was heated via three electrical resistors, as shown in Fig. 8.

The initial flow starts at 07:00. The heater is activated when the stopwatch is triggered. The water flow was recorded every ten seconds (10 seconds) with the boiling time on a table.

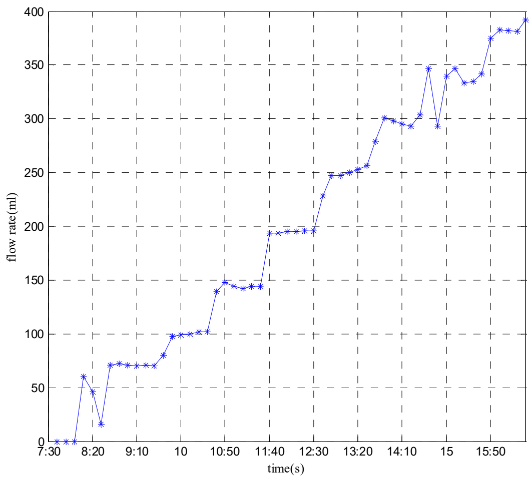

Fig. 9 Water flow rate produce (ml)

As soon as the water flows from the glass boiler, the condenser is raised to form the distillate. When the water reaches the boiling point T = 98.7 ˚C at 07:30 am condensation starts. The proposed model, already presented in Section II, has been applied and tested by PV energy sources, located at Gabes (Tunisia), with geographical coordinates defined as: latitude = 33˚52'53 "N, longitude = 10˚05'53 "E and altitude = 9 m.

The corresponding simulation and the experimental results are presented below. There are many operating parameters that have a direct impact on the overall productivity of the system such as cooling water flow, air flow and the temperatures of the cooling water. Additional parameters that may affect the productivity of the system are the salinity of the water, and the presence of clouds. However, these two parameters have limited effects on the productivity of the unit. For this reason, as shown in Fig. 11, the theoretical results presented are different from the experimental results.

The current theoretical model has been cross-checked and an important agreement with the trend of the experimental data has been found. Fig. 12 shows the temporal variations of power, with the variation of irradiation. We notice that the power of the resistance exactly follows the variation of the solar radiation.

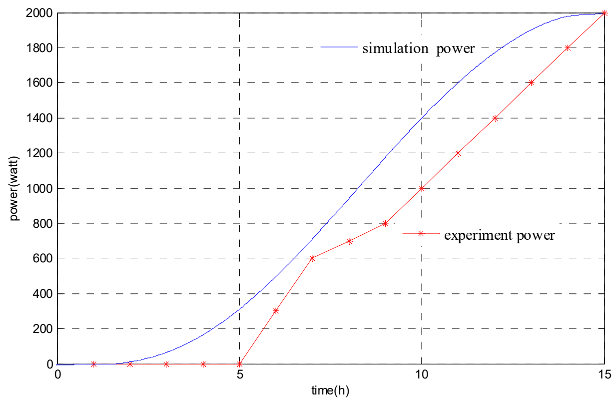

Fig. 10 Half-day PV power generation

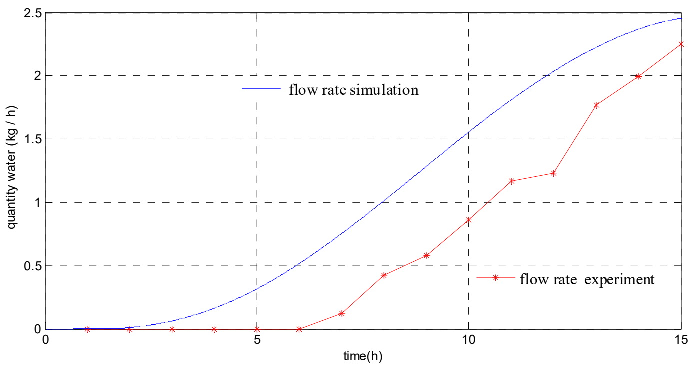

Fig. 11 Flow rate of water produced by experimentation and simulation

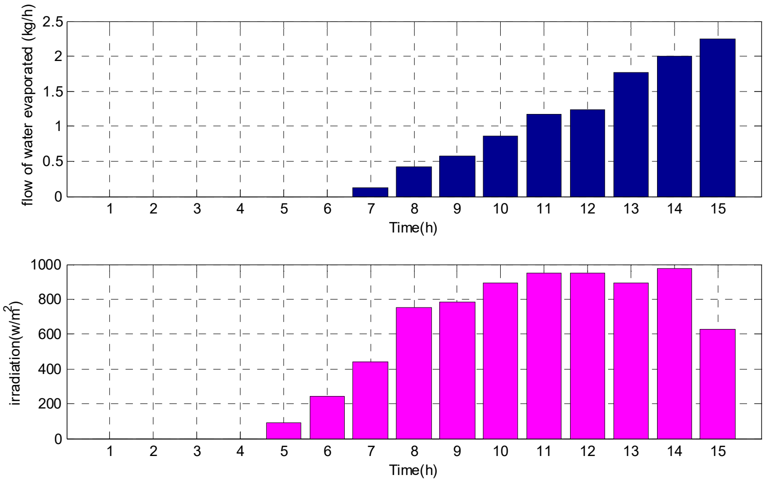

Fig. 12 Thermal performance of system

IV. Conclusion

This article illustrates the modeling, simulation and experimental study of a water desalination system, using PV sources. The system components are: a PV generator, a converter, a MPPT, an evaporator and a cooling system. The proposed system has been applied, tested and optimized on a small scale. In addition, this procedure can be used for oil extraction where efficiency is more important as the boiling temperature is low compared to that of water.

Symbols

n : diode ideal factor
k : Boltzmann constant (k = 1.38×10−23 J / K)
T : temperature on absolute scale in K
q : electron charge ($q = 1.6 \times 10^{-19}$ C)
λ : the radiation in kW/m2
ISC : the short-circuit current at 298 K and 1 kW/m^2
Ki = 0.0017 A/K is the current temperature coefficient at ISC
TREF : reference temperature (301.18 K).
I_{pv} : current of the generator PV in A
V : voltage at the output of a solar module or cell in V
RS and Rp: the series resistance and parallel resistance, (Ω)
U : the potential difference across the wire
l : length of the wire.

References

[1] R. Pavela, M. Zabka, J. Bednár, J. Tríska, N. Vrchotová, "New knowledge for yield, composition and insecticidal activity of essential oils obtained from the aerial parts or seeds of fennel (*Foeniculum vulgare* Mill.)", Industrial Crops and Products 83 (2016) 275–282.
[2] B.B. Saha, Ibrahim I. El-Sharkawy, Muhammad Wakil Shahzad, Kyaw Thu, Li Ang and Kim Choon Ng, Fundamental and application aspects of adsorption cooling and desalination, Applied Thermal Engineering, doi:10.1016/j.applthermaleng09.(2015).113.
[3] Viorel Badescu, " Verification of some very simple clear and cloudy sky models to evaluate global solar irradiance", Solar Energy Volume 61, Issue 4, October 1997, Pages 251-264.
[4] Machler, M. A. et Iqbal, M. A modification of the ASHRAE clear sky irradiation model. ASHRAE transactions, 1985, vol. 91, no 1, p. 106-115.
[5] DELORME, Claude. Bilan d'essais d'utilisation des images numériques de météosat pour estimer le gisement solaire. 1986.
[6] Gabsi, Slimane et Chehbouni, Ahmed. Solar vacuum membrane distillation for seawater desalination. In: Renewable and Sustainable Energy Conference (IRSEC), 2013 International. IEEE, 2013. p. 182-185.
[7] R. Mechlouch, A.El Jery, A.Ben Brahim, « choix d'un modele d'ensoleillement et determination des inclinaisons optimales des capteurs heliothermiques pour la ville de gabes en tunisie », Revue des Energies Renouvelables, Vol.6, N°1 juin, 2003.
[8] Sandra L Postel. Securing water for people, crops, and ecosystems: new mindset and new priorities. In Natural Resources Forum, volume 27, pages 89–98. Wiley Online Library, 2003.
[9] B.BSaha, Ibrahim I. El-Sharkawy, Muhammad Wakil Shahzad, Kyaw Thu, Li Ang and Kim Choon Ng, Fundamental and application aspects of adsorption cooling and desalination, Applied Thermal Engineering, doi:10.1016/j.applthermaleng09.(2015).113
[10] M. Farhat, O. Barambones, L. Sbita, "Efficiency Optimization of a DSP-Based Standalone PV System using a stable single input Fuzzy Logic controller," Renewable & Sustainable Energy Reviews, Elsevier publisher, 49(2015) 907–920.
[11] H. Nafaa, M. Farhat, L. Sbita, ''Modeling and Simulation of Photovoltaic Generator,'' 3ème Conférence Internationale des Energies CIER'2015, Sousse -Tunisia, 21 - 23 Dec.(2015).
[12] M. Farhat, O. Barambones, L. Sbita, "An online practical implementation of a PV system-MPPT drives based on a sliding mode approach, "Applied Energy, Elsevier publisher, Mars,(2016) http://dx.doi.org/10.1016/j.apenergy.2016.03.055 (IF :5.613).
[13] P. Surma, Comparison of methods of photovoltaic panels MPPT (P & O, IC, Fuzzy Logic) in Matlab Simulink, przeglądelektrotechnicznyl, ISSN. 90(2014) 0033-2097.
[14] M. Farhat, O. Barambones, L. Sbita, "Real-Mechlouch R, El Jery A, Ben Brahim A "choix d'un modèle d'ensoleillement et détermination des inclinaisons optimales des capteurs héliothermiques pour la ville de gabes en tunisie "Revue des Energies Renouvelables, 6 (2003).
[15] J. Battaglia, A. kusiak, J-R . Puiggali, introduction aux transferts thermique, Dunod, Paris, (2014)142-146.
[16] H. Nafaa, M. Farhat, L. Sbita, ''Modeling and Simulation OF Photovoltaic Generator,'' 3ème Conférence Internationale des Energies CIER'2015, Sousse -Tunisia, 21 - 23 Dec.(2015).
[17] H. Nafaa, S. Ouriemi, M. Farhat, S. Lassaad," Modeling and simulation of a water distiller system operated by PV panels at a real meteorological condition test" Desalination and Water Treatment (2016)1-8doi: 10.1080/19443994.2016.1172988.
[18] J. Battaglia, A.kusiak, J-R. Puiggali, introduction aux transferts thermique, Dunod, Paris, (2014)142-146